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Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

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ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/CISN) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

Seismicity in the oceanic lithosphere offshore Baja California, Mexico

In December 2012 an Mw6.3 earthquake occurred within oceanic lithosphere of the eastern Pacific plate. It occurred in an unusual tectonic setting, near a fossil trench that juxtaposes Miocene oceanic lithosphere and submerged, thinned continental lithosphere of the California Continental Borderland. This region is now hundreds of km away from the edge of the Pacific plate (Figure 1). However, it was much closer to the plate boundary earlier in its history, until subduction ceased and the continental material above the subduction zone extended as part of the evolution of the Pacific-North America plate boundary and the transfer of continental slivers to the Pacific plate (e.g., Nicholson *et al*., 1994; Bohannon & Geist, 1998).

Pacific Ocean crust west of southwest North America was formed by Cenozoic seafloor spreading between the large Pacific plate and smaller microplates. The eastern limit of this seafloor, the continent-ocean boundary, is the fossil trench along which the microplates subducted and were mostly destroyed in Miocene time. The Pacific-North America plate boundary motion today is concentrated on continental fault systems well to the east, and this region of oceanic crust is generally thought to be within the rigid Pacific plate. Yet, the December 14, 2012 Mw6.3 earthquake that occurred about 275 km west of Ensenada, Baja California, Mexico is evidence for continued tectonism in this oceanic part of the Pacific plate (Figure 1).

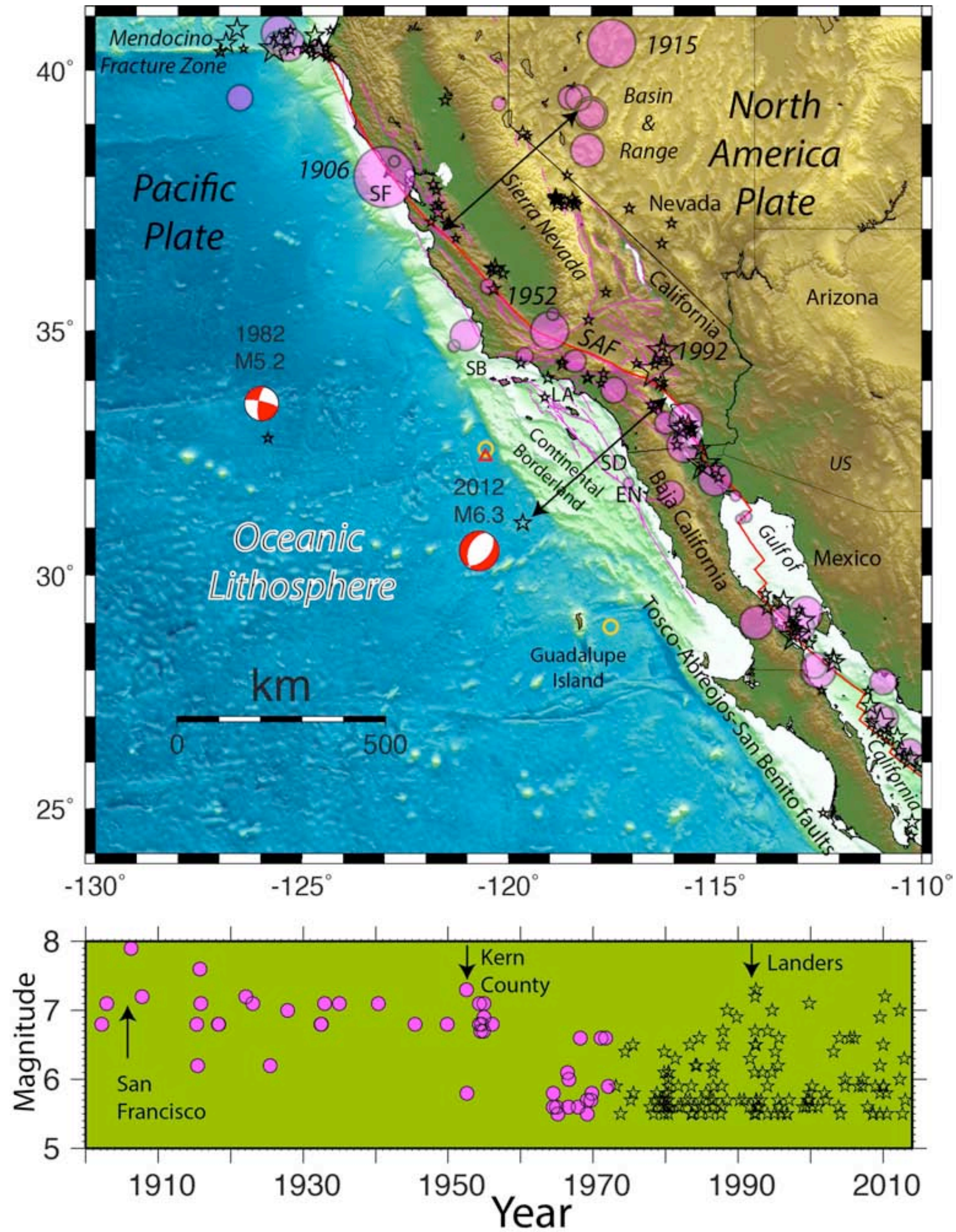

Figure 1. *Map showing M≥5.5 epicenters in the USGS PAGER catalog from 1900 to 1972 (pink circles), and the USGS PDE catalog from 1973 to 2013 (black stars). Significant events are labeled with their year of occurrence. The epicenters of the 1982 and 2012 offshore mainshocks are shown as stars with the lower hemisphere focal mechanism. The topography and bathymetry are from GeoMapApp, and plate boundary from Bird (2003) and California faults are from Jennings (1994). Red triangle represents the Dart buoy; and the yellow circles Deep Sea Drilling Project holes, 469, 470, and 470A. The black double arrows are shown to compare the similar distances from the San Andreas fault to the 2012 mainshock epicenter and the seismicity on the east side of the Sierra Nevada. EN – Ensenada; LA – Los Angeles; SAF – San Andreas fault; SB – Santa Barbara; SD – San Diego; SF – San Francisco. (Bottom) plot of magnitude versus date, showing events in the area covered by the map from the PAGER catalog as pink solid circles and from the PDE catalog as open stars. Significant events are labeled with year of occurrence.*

The preferred mainshock centroid depth of 20 km was located close to the bottom of the seismogenic thickness of the young oceanic lithosphere. The focal mechanism, derived from both teleseismic P-wave inversion and W-phase analysis of the mainshock waveforms, and the 12 aftershocks of M~3-4 are consistent with normal faulting on northeast striking nodal planes, which align with surface mapped extensional tectonic trends such as volcanic features in the region. Previous Global Positioning System (GPS) measurements on offshore islands in the California Continental Borderland had detected some distributed Pacific and North America relative plate motion strain that could extend into the epicentral region. The release of this lithospheric strain along existing zones of weakness is a more likely cause of this seismicity than current thermal contraction of the oceanic lithosphere or volcanism. The mainshock caused weak to moderate ground shaking in the coastal zones of southern California, USA and Baja California, Mexico but the tsunami was negligible.

The Mw6.3 earthquake of 14 December 2012 may be the largest earthquake recorded since 1900 in the eastern Pacific oceanic lithosphere, to the west of the continental shelf of the southwestern US and Baja California, Mexico. This area was previously considered to be aseismic, and having no significant shear strain rate. The normal faulting along a NE-striking fault plane is consistent with north-northwest stretching of the Pacific plate relative to a borderland or Baja California microplate in the Pacific-North America plate boundary zone. The occurrence of the 2012 seismicity suggests that the Pacific- North America plate boundary possibly extends 400-500 km to the west of the San Andreas fault system, including plate boundary deformation across the entire Continental Borderland and into the eastern edge of the oceanic Pacific plate. Similarly distributed plate boundary deformation is also observed in northern California, with the Sierran microplate extending the deformation 400-500 km away from the San Andreas fault into Nevada. (For more details see: Hauksson et al. 2014).

San Gorgonio Pass Stress Drop Heterogeneity

The relative motion of tectonic plates generally causes stress to build up along systems of faults. These stresses are released during earthquakes. The spatial variations in absolute stresses during earthquakes can generally not be determined directly, however, the relative decrease in shear-stress can be estimated from the radiated seismic spectrum. Stress drop estimates are based on a deconvolution of the seismic record into source, site and path effects. The seismic moment and corner frequency of the source spectrum can be used to determine rupture dimensions and stress drops if the aspect ratio and propagation speed of the rupture are assumed to be constant.

In general, seismic slip along faults reduces the average shear-stress within earthquake source regions, but individual stress drops during earthquakes are observed to vary widely in size. The details of how crustal and fault properties influence variations in stress drop are poorly understood.

To advance our understanding of variations in stress drop, we analyze source parameters of small and intermediate magnitude events within the greater San Gorgonio Pass region, southern California. The tectonics within the region are controlled by a restraining bend of the San Andreas fault system, which results in distributed deformation, and heterogeneous slip along numerous strike-slip and thrust faults. Stress drops are computed by fitting a Brune-type spectral model to individual event spectra obtained through separating the observed spectra into site, path and source contributions. The latter are obtained by iteratively removing stacked site and path terms and correcting high frequency contributions using a regional empirical Green's function. The stress drop estimates show strong regional variations from _1 to _25 MPa with a median of

4.8 MPa. We observed anomalously high stress 15 drops (>20 MPa) in a small region between the traces of the San Gorgonio and Mission Creek segments of the San Andreas fault (Figure 2). Detailed analyses of focal mechanisms reveal that stress drops are slightly higher for thrust faulting events (~6 MPa) than for normal events (~3.5 MPa).

The estimated stress drops also increase below depths of _10 km and along the San Andreas fault segments, both from north and south, towards San Gorgonio Pass (SGP), showing a negative correlation with geologic slip rates. To test the stability of our results, we conducted a sensitivity analysis of input parameters and event selection criteria, confirming the robustness of the observations. We identified crustal conditions and fault properties that contribute to local variations in stress drop estimates including the style of faulting, changes in average tectonic slip rates, mineralogical composition of the host rocks, as well as the hypocentral depths of seismic events. A detailed spatial mapping of stress drop variations can thus advance the assessment of expected earthquake ground motions (*Goebel at al*. 2014).

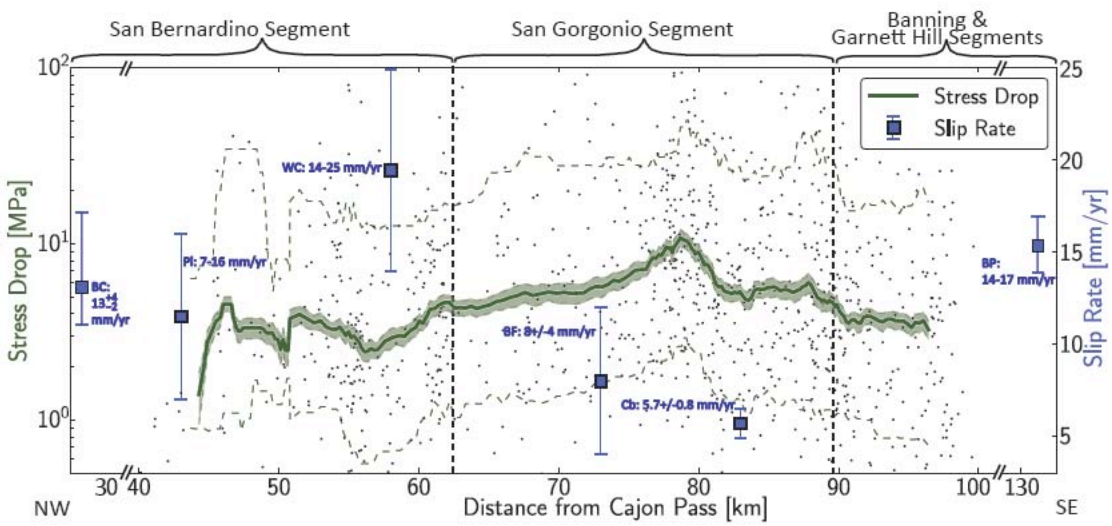

Figure 2. *Changes in stress drop for seismic events along the San Andreas fault segments through the SGP region from the northwest to the southeast within a _ 10 km wide zone. The x-axis shows the distance from Cajon pass in kilometers for a transect that passes through the sites of geologic slip rate estimates. Individual events are marked by gray dots and green line marks the median. The dashed lines show 10th and 90th percentiles. Sites of geologic slip rate estimates; BC: Badger Canon; Pl: Plunge Creek; WC: Wilson Creek; BF: Burro flats; Cb: Cabezon; BP: Biskra Palms.*

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